Case study
Hellenic Petroleum, Greece

WP3: Case studies for retrofitting

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1 Introduction to the case study

Founded in 1998, HELLENIC PETROLEUM is one of the leading energy groups in South East Europe, with activities spanning across the energy value chain and presence in six countries. The refining sector is the Group's core activity, accounting for approximately 75% of the total assets. In Greece, the Group owns three out of the four refineries operating in the country (in Aspropyrgos, Elefsina & Thessaloniki). Thessaloniki Refinery, analysed in the present case study, is an hydroskimming refinery with a capacity of 90,000 BPSD, capable of processing either high sulphur and/or low sulphur crudes, and is producing, amongst others, LPG, gasoline, and jet fuels. The aim of the current analysis is to investigate the possibility of co-feeding Used Cooking Oil (UCO) alongside conventional straight run Light Gas Oil (LGO) in an existing diesel hydrotreater unit in the Thessaloniki Refinery, from a technical, economic, and environmental point of view.

In June 2009 the "Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC" ("RED-Renewable Energy Directive") was published (EU 2009). Additionally, the amending "Directive 2015/1513" to this was published in September 2015 (EU 2015) also addressing GHG effects of indirect land use change. In December 2018, the revised renewable energy Directive 2018/2001/EU entered into force, as part of the Clean energy for all Europeans package, aimed at keeping the EU a global leader in renewables and, more broadly, helping the EU to meet its emissions reduction commitments under the Paris Agreement. Its Annex V (part C) contains a methodology for the calculation of the total greenhouse gas emissions and emission saving of biofuels (RED Methodology). This new directive establishes a new binding renewable energy target for the EU for 2030 of at least 32%, with a clause for a possible upwards revision by 2023.

EU climate action and the European Green Deal has set ambitious targets for GHG reduction by at least 55% below 1990 levels by 2030. This is a substantial increase compared to the existing target of at least 40% GHG reduction. This target sets Europe on a responsible path to achieving climate neutrality by 2050[1]. The upcoming review of RED II (scheduled for June 2021) will provide an updated policy framework to further deploy renewable energies across all sectors. The framework of RED II had been adopted before the EU agreed to pursue the climate-neutrality by 2050 and does not drive action sufficiently, both in terms of scope and timing, to reach this objective. The Impact Assessment report[2] aims to inform this political decision, investigating different policy scenarios, considered the mix of policy instruments available and how each sector of the economy can contribute to these targets. In the case of both expanding carbon pricing and moderately increasing the ambition of EE and RES policies, achieving around 55% GHG ambition arrive at the RES share of 38.4%, final energy savings 35.9%, and primary energy savings 39.7%.

[1] https://ec.europa.eu/clima/policies/eu-climate-action_en
[2] https://eur-lex.europa.eu/resource.html?uri=cellar:749e04bb-f8c5-11ea-991b-01aa75ed71a1.0001.02/DOC_1&format=PDF

Hydrotreated vegetable oil (HVO) is characterized as a premium "drop-in fuel" that can replace diesel without modifications to existing refueling systems and/or vehicles. Its high cetane number ensures efficient and clean combustion, whilst providing extra power compared to conventional biodiesel (Fatty Acid Methyl Ester - FAME). Furthermore, HVO has the advantage of not compromising fuel engine components, exhaust after-treatment devices or exhaust emissions. It can deliver up to 90% lower GHG emissions compared to petroleum-based diesel and reduce PM emissions by 33%, NO_x by 9% and CO_2 emissions by 24%. Cold flow properties can be adjusted in line with regional specifications by modifying process severity or through additional catalytic processing involving isomerization of paraffins.

HVO can be distributed in a blend with petroleum-based diesel as high as 15% v/v, more than double the maximum FAME content allowed by EN590 diesel fuel standard (7% v/v) and be used in most heavy-duty engine manufacturers and an increasing number of passenger car manufacturers as they have certified their vehicles for pure renewable diesel (RD100). Many well-proven processes for HVO production have been developed by various technology providers (e.g., Axens, Neste, Haldor Topsoe, Honeywell-UOP, Eni).

2 Case study team

The case study will be conducted by the following partners:

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3 Case study description

This section is devoted to the description of the current situation of the HELPE refinery Unit in Thessaloniki, Greece, the suggested retrofit, and what alternative would be when no retrofit takes place.

Currently, the Light Gasoil HSD unit operates only for diesel oil production. It is used to desulphurize Light Gas Oil (LGO) originating from the Crude Distillation Unit (CDU) stripper column. The main process steps in the Light Gasoil HSD unit include: (i) feed/hydrogen and recycle gas mixing and pre-heating, (ii) operation of Light Gasoil HSD Reactors, (iii) effluent cooling and separation, (iv) recycle gas scrubbing and compression, and (v) product stripping.

In the retrofit scenario, Used Cooking Oil (UCO) will be fed to the hydrotreater unit with 5% of the total processing mixture. As a result, an annual production of 22,000 tonnes of Hydrotreated Vegetable Oil (HVO) is anticipated. UCO is imported to the HELPE refinery unit over road with trucks. Upstream the pre-treatment unit there will be a storage tank installed to supply the unit with crude UCO. This storage tank will function as a collection and blending tank for the incoming feedstocks as well. The pre-treatment stage involves the degumming and the bleaching process; the later aims at removing impurities in the oil. Downstream the pre-treatment unit there will be a clean UCO storage tank installed to collect the processed oil. A third storage tank can be used as a spare tank, when other tanks are in maintenance or used to collect off-spec oil that needs to be reprocessed.

In the alternative scenario is suggested the construction of a newly refining unit producing HVO from 100% UCO. Based on available data, the minimum commercial plant size for HVO production solely from bio feedstock has a capacity of approximately 100,000 tonnes per year. For the sake of this study, the environmental performance of 100% HVO production is investigated.

4 Methodology

4.1 Supply Chain Assessment

The definition of value chain encompasses the full range of interlinked, value-adding activities that are required to make a product available to customers. The term supply chain refers to the integration of all activities involved in the process of sourcing, procurement, conversion, and logistics[3]. The supply chain assessment involves a description of UCO, with particular emphasis on its cost and availability, as well as, overviews on the UCO market and the related legal framework.

4.2 Economic Assessment

For the retrofitting scheme, a cash flow analysis is carried out. The economic indicators to be evaluated in this study are the: (i) Net Present Value (NPV), (ii) the Internal Rate of Return (IRR), and (iii) the payback period of the retrofit investment.

[3] https://keydifferences.com/difference-between-supply-chain-and-value-chain.html

The simple payback period (t_P), defined as the amount of time required to regain the value of the original investment, is calculated from the capital investment (C_0) and the annual cash flow (R_C), as follows:

$$t_p = \frac{C_0}{R_C} \quad (1)$$

NPV is an indicator of how much value an investment or project adds to the business. When the NPV is positive, the retrofit is feasible because value is added to the business. The NPV is determined by the sum of the future cash flows (C_t) generated by the investment over a series of time periods (t). The NPV is a function of the discount rate (i) and the utilization period (n) of the investment:

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \quad (2)$$

Finally, the IRR is the average interest rate paid per year. The IRR of an investment is the discount rate at which the net present value of costs of the investment equals the net present value of the benefits of the investment. In other words, IRR can be found when NPV equals zero. More profitable investments will have a higher IRR than investments of low profitability.

4.3 Environmental Assessment

Calculation of GHG emissions:

A simplified approach for evaluating the life cycle GHG emissions of biofuels is presented in the RED II Directive (Annex V, Part C)[4]. An analysis of the GHG emissions and GHG savings of biofuel according to REDII is mandatory for each amount of biofuel brought on the European market. The GHG emissions from the production and use of biofuel are calculated as follows (EU 2018):

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} \; [gCO_{2eq}/MJ_{biofuel}]^5 \quad (1)$$

where:

E = total emissions from the use of the biofuel;

e_{ec} = emissions from the extraction or cultivation of raw materials;

e_l = annualized emissions from carbon stock changes caused by land-use change;

e_p = emissions from processing;

e_{td} = emissions from transport and distribution;

e_u = emissions from the fuel in use;

e_{sca} = emission saving from soil carbon accumulation via improved agriculture management;

According to the Directive, the GHG emissions from the manufacture of machinery and equipment are not investigated.

[4] A "full LCA approach" according to ISO 14 040 of transportation biofuels might result in most cases in a higher GHG emission and thus lower GHG saving compared to the simplified approach of RED II.

[5] The emission (E) can be negative if the emission savings (e.g., e_{ccr}) are higher than the emissions from processes (e.g., e_p, e_{td})

Functional Unit - Calculation of GHG emission savings:

In line with RED II, the functional unit is defined and quantified as (EU 2018): "*Greenhouse gas emissions from biofuels, E, expressed in terms of grams of CO_2-equivalent per MJ of fuel, $gCO_{2eq.}/MJ$".* The GHG emissions savings, which are reached using biofuels, are calculated as follows (EU 2018):

$$Savings = \left(E_{F(t)} - E_{B(t)}\right)/E_{F(t)} \quad (2)$$

where:
E_B = total emissions from biofuels in [g $CO_{2eq.}$/MJ];
E_F = total emissions from the fossil fuel comparator in [g $CO_{2eq.}$/MJ].

In RED II (Annex V, part B in paragraph 19), it is mentioned that "For biofuels used as transport fuels, the fossil fuel comparator $E_{F(t)}$ shall be 94 $gCO_{2eq.}$/MJ".

5 Results and discussion

5.1 Supply Chain Assessment

UCO type & costs:

The feedstock considered for this case study is used cooking oil, also called UCO. UCO is already used vegetable oil e.g., olive oil, rapeseed oil, corn oil, sunflower oil, which is collected and afterwards pre-treated. Pre-treatment includes removal of water and solids via filtration or heating. Acid or caustic pre-treatment (free fatty acid treatment) enables neutralization. (Cocchi & Ugge, 2013) UCO is listed in the RED II Annex IX, Part B as waste-based advanced biofuel source.

The expected annual amount of UCO needed by HELPE in order to co-feed 5%, is about 25,880 tons, considering 22,000 tons annual HVO production and a conversion ratio of 85%. The international price of UCO in the last years ranges between minimum 580 €/t and maximum 865 €/ton. It is worth noting that COVID-19 affected the UCO price (Figure 1); in the beginning of 2020, the price of UCO was rising sharply, followed by a 15% drop and another increase by 11% in summer. End of December 2020 UCO price amounted to 855€/ton[6]. Future development is unclear, but it is expected that UCO market follows the UCOME (Used Cooking Oil Methyl Ester) market.

[6] https://www.greenea.com/de/analysen-markte/

Figure 1 Price effect of Covid-19 by Greenea[7]

According to REVIVE company, the average costs of UCO in Greece are between 650 € and 720 €. It is worth mentioning that UCO price is a negotiation between trader and seller and the exact numbers are not published. Currently, there is no standard price for HVO in Greece. However, according to Greenea, the price for UCO-based HVO is about 1,400 €/ton[8] (see Figure 2, values in USD/t).

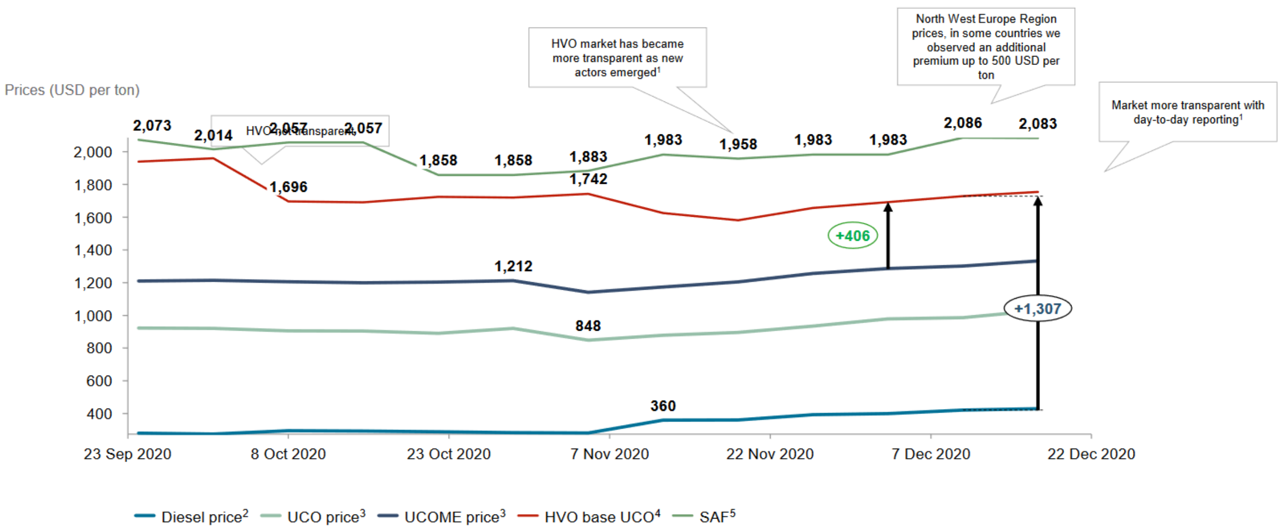

Figure 2 UCO-based HVO price in USD/t

[7] https://www.greenea.com/wp-content/uploads/2020/10/Greenea-Market-Watch-October-2020-_-EN.pdf
[8] https://www.greenea.com/wp-content/uploads/2021/01/Greenea-Horizon-2030-Which-investments-will-see-the-light-in-the-biofuel-industry-1.pdf

UCO market overview:

- *Production, collection, consumption and trade of UCO in EU:*

The total amount of UCO collected in the EU is not completely clear. According to Chrysikou et al. (2019), UCO production amounts annually to 5.6-7.2 kg/capita, divided in 50% household and 50% professional production (large end users). It has to be stated that Greece has a comparably high fresh oil consumption.

UCO collection is often divided in household UCO collection and UCO collection from professional sector (e.g., restaurants, canteens). The EU household collection systems are differently developed. In Austria, Belgium and the Netherlands, UCO collection covers all the territory of the countries, whereas other EU countries, e.g., Greece, Spain, Portugal, and UK, only have single local pilot projects and initiatives (Hillairet, Allemandou, & Golab, 2016). According to Greenea, the annual EU UCO collection in 2016 amounted to about 675,600 tons. Greenea estimated that approximately 806.000 tons of UCO could be collected in the EU from the professional sector. Among EU countries, most UCO is collected in Germany, UK, and Italy.

Regarding the UCO consumption in an EU level, a significant percentage of about 90% of UCO is used for the production of biofuels (UCOME, HVO) (Dimitropoulos & Karasavva, 2016). Since 2011, waste-based biofuels consumption in EU has tripled and UCOME consumption reached more than 3 million tons. Since most UCO is used for UCOME production, these companies are currently the biggest competitors for co-processing. However, in a long-term, drop-in biofuels, such as HVO, will be needed, due to the fact that the blending limit of conventional biofuels has already been reached. Additionally, biofuel mandates are higher than the blending limit.

As far the HVO production is concerned, HVO production capacities in the EU currently amount to 2.31 million tons, with a steady increase. According to Greenea, this amount will more than double until 2025. HVO is produced in Finland, the Netherlands, Sweden, Spain, France, and Italy.[9] Since UCO and other waste-based feedstocks are available at low cost and provide sufficient GHG emissions savings, they will be the preferable feedstock for HVO producers. The latter can buy UCO even for a higher price than UCOME producers, due to higher margins. The average spread between end-product and cost of feedstock is higher for HVO than for UCOME (Greenea, 2019). Main feedstocks for HVO production are currently tall oil, UCO, palm oil and animal fats (Flach, Lieberz, & Bolla, 2019).

Regarding trade, waste materials can acquire a value once there is a profitable use for them. For instance, UCO and tallow have a traded market value when being used for UCOME or HVO production. If conversion capacity exceeds local availability, prices will rise and can seriously affect the profitability of e.g., a retrofit. Long-term supply contracts are, therefore, a good option for de-risking (Brown, et al., 2020).

European and global demand for UCO is rising. The supply of UCO in EU does not cover local demand, so EU is highly dependent on UCO imports. Net import of UCO to the EU showed a significant growth since 2014. This could be attributed to the partly replacement of palm oil (Phillips, 2019). The amount

[9] https://demoplants.bioenergy2020.eu/

of imported UCO has accelerated during the last years due to the growing demand and has reached 1.36 million tons in 2019. About 60% of UCO is imported, more than half of it from Asian countries, such as China, Indonesia, and Malaysia (see Figure 3).

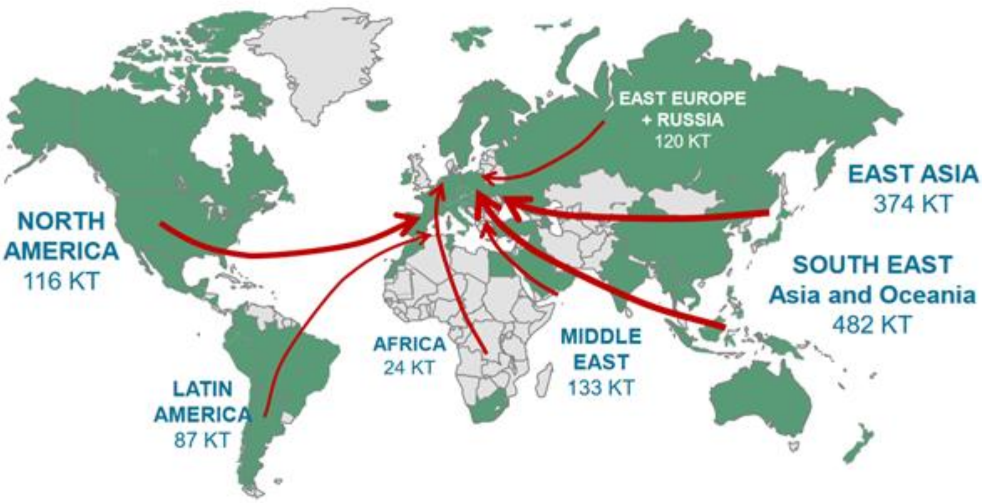

Figure 3 UCO exports to the EU in 2020[10]

In future, trading between China and Europe will shift from UCOME to UCO, since European HVO production, and therefore UCO demand, is increasing. Simultaneously, China is increasing domestic UCO demand, due to increasing UCOME and HVO production capacities (Greenea, 2019). UCO sourcing within the EU has limited growth possibilities. Additionally, local demand in Asia is increasing. This results in an overall decline in global UCO availability. Furthermore, since there are currently no global standards for UCO, importing UCO from outside the EU could result in quality, sustainability, and traceability issues (Phillips, 2019).

- *Production, collection, consumption and trade of UCO in Greece:*

The Greek Ministry of Environment and Energy is estimating UCO production of 55,200 tons/a, based on a multiplier of 5kg/capita. According to YPEKA, total UCO collection in Greece (for energy production) amounted to 26,767 tons in 2018. UCO collection in Northern Greece amounted to 1113 tons, mainly from the municipality Edessas.

UCO collected in Greece is sourced mainly from the professional sector. However, there are also public awareness campaigns (e.g., newspapers, TV, school workshops, etc.) in order to increase household UCO collection. Reasons for the currently small amount of household UCO collection in Greece could be a lack of infrastructure and industries that refine UCO for biofuels production. It is worth noting

[10] https://www.greenea.com/wp-content/uploads/2021/01/Greenea-Horizon-2030-Which-investments-will-see-the-light-in-the-biofuel-industry-1.pdf

that the total collectable UCO in the country is estimated at 46,000 tons; 26,000 tons/a come from the professional sector and 20,000 t/a from households.

In Greece, there are about 50 companies collecting and transporting UCO. UCO is mainly used for UCOME production and sold untreated. UCO is considered as waste; therefore, an environmental permit to be stored is required. This results in large UCO collectors having their own storage facilities and small collectors storing their UCO also at these storage facilities (Dimitropoulos & Karasavva, 2016). Some UCO suppliers of Greece are PRASINO LADI, AGROIL ENERGY, REVIVE, Michaelis Sons GP, E. KAROUZAKI – P. PAVLIDIS G.P., and FYTOENERGEIA S.A.

Regarding the UCO consumption in the country, beneficiary biodiesel distribution companies must use the quantities of raw materials documented in Law 3054/2002 in FEK B' 1248/2020. The total distribution of biodiesel in Greece market amounted to 178,665 kl. The total amount of biodiesel produced from the corresponding amounts of vegetable oils, UCO, and animal fats (implemented in double counting) is about 47,714 kl.

Even with a high fresh oil consumption, the amount of UCO collected in Greece is estimated not to be sufficient for co-processing. Therefore, import of UCO will be necessary, e.g., from Ukraine. The RED II Directive as well as other regulations, do not distinguish between domestically collected UCO and one which is imported from third countries. However, when importing UCO, sustainability and traceability should be ensured. It has to be considered that UCO requires a certification.

Legal framework in Greece:

UCO is listed in the RED II Annex IX, Part B as waste-based advanced biofuel source and it is eligible for double counting. HVO from UCO is capped with 1.7% of national road and rail transport consumption. Co-processing of UCO to produce HVO in the Thessaloniki refinery of HELPE is remaining within the limits of the cap and the current HELPE market share.

5.2 Economic Assessment

Co-feeding UCO in the existing Thessaloniki refinery requires substantial capital expenditures, including all costs required for (i) installing the pre-treatment unit, (ii) cleaning extensively the UCO before being fed to the hydrotreatment unit, and (iii) modifying the Light Gasoil HSD unit. The consumption of UCO is the main operational expenditure; it accounts for 87% of the additional operation costs. On the other hand, the costs associated with the cleaning of the UCO are found to be negligible. However, there is a need for an extensive increase in make-up gas to be used within the Light Gasoil HSD unit to hydrotreat the UCO; this increase is reflected by a moderate increase in costs of the Light Gasoil HSD utilities.

The suggested retrofit was found to be economically feasible with an IRR of 13% (> 8% reference discount rate) and a payback period of about 8 years. However, a potential increase in the buying price of UCO will result in lower IRR and NPV figures. On the contrary, if the selling price for the green product increases, both the IRR and NPV figures will also increase. Only if the UCO price increases above 768 €/ton, or the selling price of the green LAGO product decreases below 1313 €/ton, the retrofit will become economically unattractive. In all other cases, the suggested retrofit represents an economically feasible investment, compared to the overall investment cost.

5.3 Environmental Assessment

Calculated results indicate the current operation of the Light Gasoil HSD unit has the worst environmental performance, mainly due to the CO_2 intensive processes of LAGO production and diesel combustion. The relevant GHG emissions are estimated at 104.52 g $CO_{2eq.}/MJ_{biofuel.}$ On the other hand, co-feeding UCO and LAGO - in a 5/95 ratio - shows positive results towards lowering overall GHG emissions. This could be attributed to: (i) the modifications required to make co-feeding possible and (ii) the zero emissions from the combustion process of the HVO fuel due to its biogenic origin. The estimated GHG emissions for the suggested retrofit are 100.04, 100.10 and 100.15 $CO_{2eq.}/MJ_{biofuel}$, for transport distances of 500, 1000 and 1500 km, respectively. It was found that the selection of the location of the waste UCO collection centers – within a transport radius of 1500 km – is not an important factor from an environmental perspective; the difference on environmental burdens between the five cases are below 0.2%.

The environmental benefits of co-feeding LAGO and UCO into the hydrotreating unit are demonstrated by calculating the emissions avoided (savings) from the HVO production from UCO; they reach about 4.2% for all transport distances investigated. Although the fuel consumption in the suggested retrofit is less that the corresponding one of the current situation, the increased hydrogen production calls for higher make-up rate, with this rate being produced in the CNR unit via highly endothermic reactions.

The high emissions savings (about 86%) to be incurred by the construction of a newly refining unit using 100% UCO as feedstock, indicate that further investigation needs to be done with respect to the environmental impacts of clean fuel production processes. However, due to max cap on UCO usage imposed by RED II legislation, alternative sources of bio feedstock will have to be considered.

5.4 Risk Assessment

In order to decide on the investments, a risk assessment was carried out along with a ranking for aspects of great importance. The risk assessment findings showed that the most significant factors associated with the supply chain of UCO (high importance) are the availability and price of UCO, as well as, the legal environment regarding the UCO import. The risk related to the feedstock availability refers either to problems in imports from other countries or to the lack of feedstock on a national level. Regarding the refining process, the most important factor (high importance) is the lack of provision of financial incentives by the Greek government. The legal framework should recognize that biofuels contribute to the energy transition attempted by the EU. Governmental decisions on regional, national and international level are crucial for the future of such an investment. Last, but not least, the most important factor associated with the HVO distribution (medium importance) is the competitive price of HVO compared to alternative fuels. In every case the project should be designed in a way to provide resilience and secure constant processing.

6 Key Performance Indicators (KPI)

The technical, economic and environmental KPIs investigated in this study, are summarized in Table 1.

Table 1 KPIs results on HELPE Case Study

KPI	Value
Increase in biomass converted per year	25.9 kt/y
Increase in bioenergy or biofuel generated per year	22.1 kt/y
Internal rate of return (IRR)	13.0%
CAPEX reduction compared to alternative	-
Carbon dioxide Equivalent Emission Reduction of supply chain and operation	4.2%
Increased efficiency of resources consumption	5%

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